Environment template (REF5)

Institution: Liverpool John Moores University

Unit of Assessment: UoA 9 (Physics)

a. Overview

Research in Physics at LJMU is carried out solely within the Astrophysics Research Institute (ARI). The ARI resides within the Faculty of Science, as one of four Schools in this Faculty. The Institute is represented on the Faculty Management Team and all Faculty Strategy and Operational committees. With the appointment of nine new academic staff, plus additional PDRAs, research students and support staff, the Institute moved to a new building situated in the centre of Liverpool between LJMU and the University of Liverpool in Liverpool Science Park in June 2013.

Oversight of the ARI is through the Institute's Advisory Board, which provides strategic advice on all activities, including feedback on the allocation of staffing and financial resources between activities, ensuring that the Institute stays focussed on delivering outstanding international research. The Advisory Board comprises three external members and a representative of University senior management. Day-to-day management is through the ARI Management Board, chaired by the Director, and involving representatives for all core activities (Research, Teaching, Liverpool Telescope (LT) and Technology Development, and Public Engagement), and including a representative of the research students.

Unlike most other astronomy and astrophysics groups in the UK, the ARI does not sit within a larger physics department (although our main teaching efforts are on the Joint Degrees in Astrophysics with the University of Liverpool Department of Physics where ARI staff are accredited lecturers) and all the staff returned by LJMU under UoA 9 are astrophysicists. Although there are three main research themes within the submission (Star Formation, Time-Domain Astrophysics and The Structure and Evolution of Galaxies), individual staff members often work in more than one, or indeed all of these areas. Consequently the submission itself is not divided into separate research groups.

b. Research strategy

Implementation of our RAE2008 Strategy

In our RAE2008 submission we defined a number of goals, many of these have been achieved, and some have been exceeded:

- We planned to make two new senior academic appointments, but with funding from the University Strategic Investment "Inspire" campaign to recruit outstanding academic researchers to LJMU's identified beacons of excellence, we have made nine appointments, all of whom are category A staff in this submission, and significantly strengthen our key research areas. Two of these also support the LT and its successor. More detail is given in Section (c).
- We proposed to construct a fast read-out CCD camera, RISE, in collaboration with Queen's University Belfast. This instrument became fully operational in 2008.
- We planned to complete the FRODOSpec spectrograph for the LT; this became fully operational in 2009.
- We planned to exploit the RINGO polarimeter on the LT, and with support from the University and a Project Research and Development grant from STFC we have extended this programme to deliver next generation polarimetric instruments, RINGO2 and RINGO3 (now operational).
- We proposed to increase the field size of the LT optical detector and to do this we have built a new instrument, IO:O, incorporating a new E2V 231-84 CCD. The field size of the new instrument is 10 x 10 arc minutes and it is now fully commissioned.
- We proposed to increase the field size and extend the wavelength range of the LT Infrared detector (IO:I), incorporating a Teledyne Hawaii-2RG array, which increases the field size from 1.5 x 1.5 to 6 x 6 arc minutes, and was installed in late 2013.
- We intended to pursue our involvement with Robotic Telescope Networks, including the Faulkes and Yunnan telescope projects. Although we have pursued scientific involvement, we

use these telescopes on a stand-alone basis, and our efforts have been redirected into the development of a successor to the LT, and to membership of the Large Synoptic Survey Telescope (LSST) and intermediate Palomar Transient Factory (iPTF) consortia (see below).
- We had contributed direct funding to the e-MERLIN radio interferometer hardware, and planned an e-MERLIN legacy program. We are Co-PI of the e-MERLIN legacy survey AGATE, awarded 330 hrs in 2012 and the first science data have recently been obtained. We had an STFC-funded PDRA supporting this activity in the period.
- We proposed to join the LOFAR-UK consortium, providing a UK station and other involvement in the Dutch-led Low Frequency Array. We are a member of LOFAR-UK and the Rawlings Array was opened at Chilbolton in July 2013. We wrote the science case for WEAVE follow-up of LOFAR sources (see below). We are centrally involved in the search for LOFAR radio transients and have developed software to facilitate rapid response to alerts via VO events**.**
- We contributed towards the purchase of narrow-band filters for the VISTA survey telescope and have published results on star formation at high redshift using VISTA and Subaru data together with the associated completion of a PhD programme.
- We proposed to concentrate resources on high profile collaborative research programmes led from Liverpool, including AAOmega/GAMA and the HST/ACS Coma Cluster Treasury Survey, which have produced 29 and 13 publications in refereed journals respectively.
- We reported that Moore is UK PI of the JCMT/SCUBA-2 Galactic Plane Legacy Survey. SCUBA-2 started science observations in March 2012 and data are still being gathered. Moore currently leads the writing of the first Galactic Plane Legacy Survey paper.

Research Strategy for 2014 – 2020

Within our three science themes our objectives focus on fundamental questions in the field: the origin and properties of the stellar initial mass function; physics in extreme environments; the structure of the Milky Way; and the evolution of the baryonic content of galaxies and clusters. These align with the key questions in the ASTRONET long-term Science Vision and the identified Science Challenges in the STFC Roadmap.

We have appointed new staff in all of our key areas. They were recruited from a strong pool of international applicants, and all have outstanding research records. Our strategy for 2014 – 2020 is to underpin these new appointments with the addition of younger staff on personal fellowships, PDRAs supported by STFC, EU, Leverhulme Trust etc., and additional research students, from both internal and external funds (LJMU announced a new internal studentships fund in 2013).

Our aspirations are supported by exploitation of new facilities and technological developments in which the UK has a significant involvement:

- We are a key partner in the WEAVE spectrograph for the William Herschel Telescope (WHT), which received a recommendation from STFC Science Board for full UK funding in November 2013, and which forms the basis of our involvement with the ESA GAIA mission to study the formation and structure of our own galaxy by measuring phase space co-ordinates of 10^9 stars. WEAVE will measure radial velocities and chemical compositions of stars as a complement to GAIA astrometric information**.** WEAVE also further cements our involvement in the Dutch-led LOFAR project, through its cosmology and galaxy formation surveys.
- After successful Cycle 0 & 1 ALMA observations in the area of Star Formation, we have identified key European partners and will lead applications to any forthcoming ESO call for ALMA Legacy proposals.
- LJMU has signed an MoU with the Astrophysics Research Committee at the University of Washington to join the Sloan Digital Sky Survey IV (SDSS-IV) consortium. The primary objectives are the exploitation of a core SDSS-IV science survey, APOGEE-2, which will study the 3-D chemical composition distribution of stars in the Galaxy, and the spectroscopic identification of sources from the eROSITA satellite (the SPIDERS survey) for the purpose of studying the high redshift population of X-ray clusters.
- We have been invited to become a partner on the iPTF project. We will exploit our access to both real-time alerts, in conjunction with LT, and the PTF data archive to further our research

aims in Time-Domain Astrophysics, particularly in the areas of novae and supernovae.
- Since June 2013 ARI has been an associate member of the Čerenkov Telescope Array (CTA) consortium. This will be a major astroparticle physics experiment which provides a new window on the high-energy universe, and a complementary technique to study astrophysical shocks and compact sources in all three of our existing research themes.
- We are in the process of securing international affiliate status in LSST, scheduled to begin scientific operations around 2020, either individually or as part of a national consortium. Our research interest in LSST focuses on transients, AGN and galaxy clusters.
- Our involvement in the ESA Euclid satellite will focus on the evolution of galaxy bulges and disks along with a study of the origin of the low-luminosity dwarf galaxy population. As a Euclid Independent Legacy Scientist and part of the EUCLID science team, Baldry will be central to coordinating this activity, along with named collaborators Collins, Mundell and James.
- Through the LT, ARI holds a leading position in many rapidly growing areas of Time-Domain Astrophysics, and we will consolidate that lead through development of a successor telescope. New US-led facilities such as LSST focus on finding new transient objects, so our strategy is to focus on understanding their astrophysics. This can only be accomplished by facilities that provide coverage of the time domain on a wide variety of timescales (from seconds to years) with multicolour and, crucially, spectroscopic capabilities. Once LSST comes online, both the increased rate of transients and their fainter magnitudes mean that a ~4m class robotic facility will be needed to provide spectroscopic follow-up. LJMU have therefore invested £200k for staff and associated costs in developing a detailed scientific and technical case for a successor to LT. LT2 will be larger (~4m diameter) and possess a faster response time than LT. The funded study will be complete by mid-2015, by which time we will have identified funding partners, and will have developed a construction plan leading to first light around the same time as LSST.
- Utilising the rapid response capability of LT and then LT2, we will conduct electro-magnetic observations of gravity wave candidates from the Advanced LIGO/VIRGO experiments as their sensitivity and localization accuracy improves. Our letter of intent of August 2013 was well received and negotiations are proceeding towards an MoU covering the initial detections.

Strategy for High Performance Computing

McCarthy and Font are associate members of the Virgo Consortium, and through it have access to some of the largest HPC facilities in Europe. We plan to establish the ARI as an official Virgo node with them as Co-Is on upcoming proposals for ERC and Marie Curie training grants. Local computing hardware at the ARI necessary for analysis of simulations carried out on HPC facilities is, and will continue to be, funded through research grant applications led by McCarthy and Font.

c. People, including:

i. Staffing strategy and staff development

LJMU supports and develops World-leading research, and selected the ARI as one of two key departments to receive the major benefit from the University's "Inspire" strategic initiative, which brought nine new staff to the ARI. Our policy is to seek the widest pool of international applicants for any new academic or research posts. Of the new staff appointments, five went to non-UK citizens. The new staff recruited were:

- Nate Bastian, formerly a Senior Scientist at the Excellence Cluster "Origin and Structure of the Universe", Munich, Germany, who was appointed to a Chair at LJMU in 2012. He also holds a Royal Society University Research Fellowship. He is an expert in young stellar clusters, populations in globular clusters, the stellar mass function, and starburst galaxies.
- Chris Copperwheat, formerly of the University of Warwick, who was appointed to the new position of 'Liverpool Telescope 2' (LT2) Project Scientist in 2012. Working alongside Steele, he leads the design study which will result in a detailed proposal for the next generation LT. He also has a significant research record on cataclysmic variable stars and related systems.
- Ben Davies, formerly at Cambridge, who was appointed to a Senior Lectureship at LJMU in 2012 bringing with him a Royal Astronomical Society Fellowship. He is an expert in galactic

massive clusters, stellar evolution, metallicity gradients in galaxies, and massive stars.

- Chris Davis, formerly at NASA Astrophysics Division, Washington, DC, who was appointed to the new position of Liverpool Telescope Astronomer in Charge in 2012. His research record concerns infrared observations of young stellar objects, and infrared survey astronomy.
- Andreea Font, Royal Society Dorothy Hodgkin Fellow, formerly at the University of Birmingham, who was appointed as a Senior Lecturer at LJMU in 2012. She is an expert in galaxy formation, satellite galaxies and the structure of the Milky Way.
- Steve Longmore, formerly at the European Southern Observatory, Garching, Germany, who was appointed a Senior Lecturer at LJMU in 2013. He is an expert in progenitor gas clouds of clusters, the origin of the IMF, structure of the ISM, and star cluster formation.
- Ian McCarthy, STFC Advanced Fellow, formerly at the University of Birmingham, who was appointed as a Senior Lecturer at LJMU in 2012. He is an expert in galaxy and cluster evolution and brings theoretical expertise in hydrodynamic simulations. Together with Font, he is an associate member of the Virgo consortium, and is part of the team carrying out the EAGLE simulation, a new milestone in hydrodynamic simulations with an improved treatment of sub-grid physics and supernova/AGN feedback.
- Paolo Mazzali, formerly at the Max-Planck-Institut für Astrophysik, Garching, Germany, and at INAF, Osservatorio Astronomico di Trieste, who was appointed to a Chair at LJMU in 2012. He is an expert on supernovae and GRBs.
- Ricardo Schiavon, formerly at the Gemini Observatory, Hawaii, USA, who was appointed to a Readership at LJMU in 2012. He is an expert in stellar populations within globular clusters, and galaxy evolution. He is also survey scientist for APOGEE, an infrared radial velocity and chemical abundance survey of the stellar population of our galaxy, which is part of the SDSS-III programme. He strengthens our involvement in GAIA, WEAVE and SDSS-IV.

Bastian, Davies, Longmore and Schiavon form a new Stellar Clusters group within the ARI, but their research interests overlap with several existing staff: Moore, Mundell, Salaris and Percival, and their arrival links our strengths in Star Formation and The Structure and Evolution of Galaxies. McCarthy and Font, greatly strengthen The Structure and Evolution of Galaxies research theme, working closely with Collins and Baldry. Mazzali strengthens the supernova research strand within the Time-Domain Astrophysics theme, working alongside Bersier and James. Copperwheat and Davis strengthen the Liverpool Telescope group, working alongside Steele and a team of engineers and programmers, whilst also strengthening our Time-Domain Astrophysics (with e.g. Bode and Darnley on novae) and Star Formation research themes respectively.

As well as providing a commitment of around £600k p.a. in additional long-term pay costs to ARI, these new posts have also been underpinned by supplementary funding. This includes the allocation of 3 new research studentships, match funding to create 2 STFC STEP PDRAs and £10k additional special meetings funds. In addition, the LT2 feasibility study has been allocated £140k non-pay costs over two years as part of the strategic initiative. Most recently, in the 2013 grants round, STFC funded an additional: 1 PDRA each for Davies and Longmore; 15% Staff FTE for each of Davies, Longmore and Mazzali and a 100TB server for McCarthy. This amounts to 85% of the total cost requested, and is awarded under STFC's New Applicants Scheme as an enhancement to our current Consolidated Grant.

Career Development Support

New starters to the University attend a research induction programme and gain an overview of relevant professional services alongside the policy and procedural frameworks that underpin research at LJMU (research strategy, grant funding and support, research ethics, library resources, REF, Researcher Development Framework and associated training needs). LJMU's annual Personal Development and Performance Review recognises research and related career development as distinct elements within it, enabling discussions around career training and guidance. LJMU supports and implements the Concordat to support the career development of researchers. ARI Early Career Researchers are mentored by more experienced researchers within the same research themes.

A formal workload allocation model operates across LJMU. All research-active staff receive a research allocation, which abates their required teaching time. This is reviewed annually by the Faculty of Science Research Strategy Committee, which bases its decisions upon research output. Newly appointed staff receive an automatic abatement for a minimum of 3 years.

The University invites applications on an annual basis for conferment at Reader and Professorial levels. During the REF assessment period, Salaris, Newsam and James have been appointed to personal chairs, and Bersier, Kobayashi, Moore and Baldry to Readerships. The ARI has operated a peer-reviewed sabbatical system moderated by its Advisory Board. LJMU introduced a formal, University-wide scheme in 2013. Over the REF period Collins, James, Bersier, Baldry, Kobayashi and Moore have benefited from sabbaticals under the ARI scheme.

Personal Research Fellowships

Seven submitted staff have held fellowships at LJMU during the REF period. Mundell and Maciejewski each held RCUK Academic Fellowships until 2011, and are now full members of the academic staff. Percival held an STFC Postdoctoral Fellowship to 2011, and Davies a Royal Astronomical Society Research Fellowship to September 2013. McCarthy holds an STFC Advanced Fellowship, Font a Royal Society Dorothy Hodgkin Fellowship, Bastian a Royal Society University Research Fellowship, and Mundell a Wolfson Foundation Research Merit award. Dr. Richard Parker will join LJMU in 2014 from Zurich as a Royal Astronomical Society Research Fellow working on the dynamics of young stellar clusters, and Carter, at the end of his current part-time contract, will take up a Leverhulme Emeritus Fellowship for 2 years, from January 1st 2014.

Equality and Diversity

Academic appointments and promotions to Readership and Chairs are routinely monitored (equality impact assessment) and reported in terms of equality and diversity. The University holds membership of the Athena SWAN Charter and is working towards achieving the Athena SWAN Bronze award by April 2014 in accordance with its Equality Objectives and Action Plan 2012-2017. Andreea Font holds a Royal Society Dorothy Hodgkin Fellowship, for which female candidates are particularly invited to apply.

ii. Research students

In Astrophysics,19 full time students and one part-time successfully completed their PhD during the REF period, and our current student complement is 20. We receive applications from students worldwide and all shortlisted candidates are interviewed. Funding sources include STFC quota awards; internal QR and Inspire initiative monies; Thai university and government funds, and self-funding. Just under half of our completing students in the period were from overseas (one of these was a joint PhD student between LJMU and University of Lyon), and 2 were mature students.

Progress monitoring, training and support

Postgraduate research student induction is compulsory and provided by the University's Research Support Office. All research student supervisors are required to complete the University's Research Supervisors Workshop. When students first arrive at ARI, they are normally given an initial period of 2 weeks in which to discuss projects with potential supervisors and make a final choice. ARI run compulsory short courses on a range of topics designed to introduce PhD students to the wider research environment and help develop research skills. In a new initiative, up-to-date information and advice on "careers in astronomy" is now provided regularly to final year PhD students in the form of a tutorial given by a current senior research fellow.

LJMU Research Degree Regulations require that all Research Students and their Supervisors report annually on progress in line with the Code of Good Practice for Annual Monitoring. Reports are collated at Faculty level and reported to the University Research Degrees Committee.

A year after the start of the PhD all students are required to write a report in order to transfer their registration from MPhil to PhD. Then each student undergoes a viva with the supervisor and independent internal examiner. This ensures that the students demonstrate an adequate understanding of the project, show awareness of the research literature and have in place a suitable research plan for the completion of their thesis. A recommendation is then made to the University Research Degrees Committee and any necessary contingency actions (e.g. attending an internal writing course) are fed back to the student and actioned by the supervisor.

Students are valued members of the academic environment and are encouraged to participate in the intellectual life of the Institute and to develop critical and independent thinking. First and second year students present papers at journal clubs and lead the resulting scientific discussions. In addition to attending the weekly ARI seminar series, students meet with the external speakers in a closed session after each seminar, providing an opportunity to discuss with a research active astrophysicist, the content of the seminar as well as wider issues from the student's perspective. Students also organise their own biannual research conference in which presentations of their recent work are made to the other PhD students. This encourages students to support each other via feedback and discussion and by identifying areas of common activity and sharing best practice.

ARI students have benefited from the University's conference travel fund to enable them to attend UK or overseas conferences and disseminate the results of their research. Many have also applied successfully for funding from the RAS and IAU. ARI has a policy of matching financial support given to STFC quota students for non-STFC students in terms of travel and computing equipment. Students have also partaken of the INT Support and Research Studentship Programme on La Palma; have acted as STEMNET Ambassadors through the BIS/Gatsby Charitable Foundation; been selected from a field of European applicants as a participant in the 11th NEON Observing School in La Palma, and been a finalist for "The Shell and Institute of Physics Award for the Very Early Career Woman Physicist of the Year 2012", with candidates selected from across Physics. ARI funds were also used to provide extended research visits to the University of California San Diego and the University of Cape Town. As noted above, the University provided matching funds to those from the STFC STEP programme to allow 2 competitively selected students to remain with us on PDRA contracts, and one of these gained further matched funding from the Ogden Trust.

Of our students completing in the REF period, >80% remain in astronomy. Destinations are world-wide and include: ESO Fellow, Chile; Lectureships at the School of Science and Technology, Nottingham Trent University and at the Department of Physics, Chiang Mai University; Daiwa Foundation Scholarship, Japan; 3 PDRAs in South Africa; PDRA Carnegie Hubble Program, Carnegie Observatories; PDRA Shanghai Astronomical Observatory; Postdoctoral Fellow, STScI.

d. Income, infrastructure and facilities

Infrastructure in Liverpool John Moores University

With the appointment of new staff, additional research students, PDRAs and a number of support staff, the ARI had outgrown its previous accommodation in Twelve Quays House, Birkenhead, and in June 2013 moved into a new building in Liverpool Science Park jointly owned by LJMU, the University of Liverpool and the City Council. As well as providing significant extra space, this new location is centrally placed in Liverpool's 'Knowledge Quarter' between the two universities. This puts ARI within easy reach of LJMU's main city campus, and also of the University of Liverpool Physics Department where the majority of the ARI's teaching activities are carried out. Between July and October 2013, we had already held 3 international workshops at our new location. The total cost of the relocation was approximately £615k.

The Research & Scholarship Committee of the University is responsible for LJMU's research strategy, whilst the Research and Innovation Services unit provides leadership for staff and quality assurance support for research and PGR programmes. In addition to their Code of Practice for Research, they operate formal protocols for research governance and investigation of alleged misconduct. Core principles with regard to the curation of publically funded research data and outputs are explicit in LJMU's research data management policy.

The Liverpool Telescope

LT is the world's largest fully instrumented robotic telescope. It is owned and operated by LJMU and is sited at the Observatorio del Roque de los Muchachos, La Palma. Strategic and financial oversight is provided by a committee of major stakeholders (LJMU, STFC, IAC). Since operations began in 2004, LT has delivered high impact results in time-domain astrophysics. It is equipped with photometric, spectroscopic and polarimetric instrumentation, sampling timescales from ~10 ms to ~10 years. A programme of instrument upgrades is in progress: in 2012 we added a wide-field optical imager (IO) and a "lucky"-imaging camera (THOR), in 2013 we added infrared capability to IO, and in 2014 we will add a high-throughput low-resolution spectrograph. This programme is driving an increasing publication rate (currently ~50 papers/year), and is itself driven by the research needs of ARI, for example the RINGO series of polarimeters for GRB follow-up and the low resolution spectrograph for SNe typing. New instruments commissioned in the REF period have resulted in 29 ARI papers in refereed journals, some of which appear in REF2.

ARI staff currently have access to 30% of time on the LT and we anticipate that this will increase over the next REF period. In line with our submission to the 2013 STFC Programmatic Review, we have developed a future funding model that allows development of strategic funding and time allocation partnerships, building on those that now exist with ESA (GAIA tracking), Oxford (LOFAR follow-up) and University of Slovenia (GRBs) and anticipating major future collaborations such as the proposed successor to iPTF (the Zwicky Transient Factory). We have also agreed to increase the proportion of NSO time on LT to 10% in line with LJMU OFFA funding and will build further strategic partnerships in public engagement through the next REF period.

The robotic operations model pioneered by LT presents large advantages over conventional observatories in terms of operating costs, environmental impact (less travel) and the range of accessible timescales and cadences. The technologies developed, particularly in optimized scheduling and autonomous rapid follow-up, are being applied both within traditional ground-based observing (e.g. WEAVE) and wider fields (e.g., laser ranging and geodetic observatories). Synergies with projects such as CTA are being actively explored.

In 2011-12 LJMU invested £340k in constructing a new support building on La Palma providing electronic, optical and mechanical workshops, and storage and office facilities in order to improve the efficiency of visits to the site by LJMU staff. The effect of this investment is demonstrated by the reduced technical downtime of the telescope following the work (average 2.4% in the period January 2012-October 2013 compared to 5.4% in the equivalent period in 2010-2011)

From 2014 LT will form a key component of Gaia transient followup, allowing maximal scientific return during the mission (rather than waiting for the eventual catalogue releases). In addition LT will be the lead European telescope in the mission-critical Gaia Ground-Based Optical Tracking workpackage which is essential to allow the full astrometric precision of the facility to be attained.

Use of SRIF and RCIF resources

In addition to external funds from STFC, the Royal Society, EU and others, as detailed in REF4, the University prioritised ARI when deciding on the distribution of SRIF and RCIF funds. Against agreed plans, the ARI received a total of £962k via these routes in the REF period. The majority of this was utilised in support of enhanced LT operations and development.

e. Collaboration or contribution to the discipline or research base

Policy

Bode was an expert witness at the House of Commons Science and Technology Committee inquiry into Astronomy and Particle Physics, 2011. He was an Executive Board member and Roadmap Task Leader for the ASTRONET European long-term planning exercise conducted on behalf of the major funders of astronomical research in Europe.

Awards and prizes

Mundell holds a Royal Society Wolfson research merit award, Baldry and Collins are part of the group which received the RAS Group Award (2008) for the 2dF Galaxy Redshift Survey. ARI staff hold senior visiting appointments internationally at Bologna, Tokyo, Shanghai, both MPA and MPE Garching and the Hebrew University of Jerusalem.

Conferences organised in Liverpool

ARI has organised several major conferences in Liverpool, including the ASTRONET Roadmap Symposium (June 2008, with over 300 delegates from across Europe and beyond), a major symposium on Gamma-Ray Bursts in the era of rapid followup, co-sponsored by the RAS and STFC (June 2012), and three further one-day RAS discussion meetings (The Luminosity Function of Galaxies, 2009; Explosive Transients, 2010; Galaxy Cluster Scaling Relations, 2011). Smaller workshops are organised frequently by ARI staff; at least 19 have taken place over the REF period.

SOC Chairs, memberships, invited lectures at international conferences and reviews

Over the REF period submitted staff have served on the Scientific Organising Committees of 35 major conferences, 12 as chair or co-chair. They have given 112 invited reviews, keynotes, or other invited talks at international conferences. Bastian was first author of an invited review for Annual Reviews of Astronomy and Astrophysics (2010).

National and International Peer Review

ARI staff have been members or chairs of a broad range of STFC committees, including Science Board, PPAN, the Astronomy Grants Panel, the Projects Peer Review Panel, the Ernest Rutherford Fellowships selection committee, advisory committees for MERLIN, SWIFT/XMM-Newton and ALMA, and the Science in Society Advisory, Large Awards and Fellowships panels. They represent STFC on international Boards for JCMT and WEAVE. In total, submitted staff have had 21 chairs or memberships of UK funding committees, and 19 of International review, funding or facility time allocation committees, including the NWO ASTRON quinquennial Evaluation Committee, the EU ERC Starting Grants committee, the International Scientific Advisory Committee of the National Astronomical Research Institute of Thailand, the Scientific Council of the P2IO Laboratoire d'Excellence Saclay, and the International Advisory Board for Onsala Space Observatory.

International collaborations and key projects

Our involvement in international collaborations is discussed in Section (b) above, and includes: LOFAR, WEAVE, SDSS-IV, iPTF, CTA, LSST, Euclid, Advanced LIGO/VIRGO gravitational wave detectors, the Virgo and EAGLE cosmology collaborations, GAMA, the JCMT and e-Merlin Legacy programmes, and the HST/Coma Treasury survey. In addition, LJMU is a member of the EU OPTICON collaboration, staff members are active participants in the European Science Foundation GAIA/GREAT consortium and Moore is a member of the science team for the ESO/ELT METIS instrument.

Public Engagement and Collaborations with Industry

Public Engagement, principally through the National Schools' Observatory and Spaceport, is integral to the research work of the ARI and forms an important strand of our future strategy. The LT project at Liverpool JMU has a long tradition of strong industrial engagement. The project has ongoing strong links with a number of local engineering companies. We have also had success in licensing software and hardware developed for the telescope to the Faulkes/LCOGT organization. Licence income of £160k plus telescope time worth an additional £180k on LCOGT telescopes has been received by LJMU from this activity to-date. Our work in Public Engagement and Industrial Development is described in detail in REF3a alongside three associated Case Studies in REF3b.